

Article

Research on Wildfires and Remote Sensing in the Last Three Decades: A Bibliometric Analysis

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Abstract: Evaluating the impact of wildland fires on landscapes, a pursuit increasingly supported by remote sensing techniques, requires an understanding of wildfire dynamics. This research highlights the main insights from the literature related to “wildfires” and “remote sensing” published between 1991 and 2020. The Scopus database was used as a source of information regarding scientific production on these topics, after which bibliometric tools were employed as a means through which to reveal patterns in this network of journals, terms, countries, and authors. The results suggest that these subject areas have undergone significant developments in the last three decades, having been the focus of growing interest among the scientific community. The most relevant contributions to the literature available have been made by researchers working in the areas of earth and environmental sciences (54% of the publications), primarily in the United States, China, Spain, and Canada. Research trends in this field have undergone a significant evolution in recent decades, explained by the strong relationship between the technological evolution of detection methods and remote sensing data acquisition.



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Keywords: forest fire; worldwide; scientific research; literature review; bibliometric analysis

1. Introduction

Fire plays a key role in the ecology of many ecosystems [1,2], having been present throughout the history and the development of society. It can also be considered a determining factor in the distribution and dominance of savannas worldwide, even in places where the climate and soil could potentially sustain forests [3–5]. Thus, fire can be understood as a natural ecological factor that influences the structure and functioning of several ecosystems [6]. However, a distinction must be made between fires and wildfires, the latter being defined by their uncontrollable nature, causing significant losses [7].

A severe threat to many environments, wildfires are considered one of the most challenging phenomena in environmental sciences [8]. The increase in frequency and intensity of fires has been documented in several ecosystems around the world [9–11], producing a significant impact on global warming, as fires often result in a considerable loss of biomass and carbon, which can alter local climates [2,7,12–16].

In this context, remote sensing techniques are a highly feasible and effective tool for describing patterns of the occurrence of fire in various ecosystems, as satellite imaging is an important means through which to delineate the perimeters of fire expansion and characterise the degree of intensity or severity reached by fires [12,13,17–21].

The assessment of changes in vegetation patterns caused by fire over time can be conducted in various ways, from traditional field observations to monitoring carried out using Earth Observation Systems [22]. Earth observation is an important tool for monitoring land surface and vegetation dynamics at regional and global scales over significant periods of time [23,24]. Although their temporal, spatial, and spectral resolutions vary, the various Earth Observation Sensor systems available provide tools with which to assess vegetation

attributes from different perspectives [22]. In addition, recent advances in computational methods and free access to medium spatial resolution images, such as Sentinel and Landsat, favour their applicability in studies involving the use of time series to identify disturbances and monitor events [22].

However, some limitations of these methods should be noted, such as cloud cover, which could affect data quality in a given area and make it difficult to identify the fire. Another limitation may be the availability of free data and the relationship to the extended temporal resolution of some sensors, which may make it difficult to quickly acquire data following a fire [25].

An increasing number of studies related to wildfires have been developed since remote sensing applications began gaining popularity [26]. As such, studies must be conducted to present a comprehensive review of the investigations carried out in order to understand the patterns of research in this field. Bibliometric analyses based on mathematical and statistical tools have been carried out to analyse publications, citations, and journals relating to many areas of knowledge [27–29]. Researchers can use bibliometric maps to better understand the field in which they are working [30], using scientific methodology to determine the evolution of research on the topics in question (wildfires and remote sensing).

Bibliometrics can be commonly defined as a qualitative and quantitative analysis of research used to assess the impact a researcher, research groups, institutions, countries, or journals have had [27–29,31]. Therefore, adopting bibliometric analysis is an appropriate approach to highlight the main results of the literature [28,31,32] and reveal the main knowledge gaps [28,33]. Consequently, bibliometric analyses, along with text mining techniques, can help recognise standards in a scientific body of literature [34,35]. This is important as it enables an analysis of the thematic, methodological, and conceptual trends, taking into account their variations over time, supporting knowledge perception and structuring both developing and consolidated fields of science [34,35].

Although some review studies involving wildfires in conjunction with the use of remote sensing techniques have been proposed [20,25,26,36–39], it was considered important to list and map the main conceptual and methodological trends, identifying significant theoretical contributions and describing their applications through case studies developed in different parts of the world. Considering the need for a structured revision to be carried out of scientific production addressing the research topics, the objective of this paper is to analyse the scientific publications indexed in the Scopus database, simultaneously encompassing the subjects of forest fires and remote sensing over a 30-year timescale.

As such, the following research questions were proposed to guide the study: (i) Which are the leading scientific journals to address these subjects? (ii) Which are the main countries and research institutes to publish on these subjects? (iii) Which are the most frequent environmental indicators referred to in the publications? (iv) Which authors publish the most?

2. Materials and Methods

To answer the questions proposed, research was based on a bibliometric analysis approach. Thus, quantitative data from reference articles were used to produce graphs, tables, bibliographic data networks, and textual data networks. In terms of a methodological approach, the study was divided into two main stages. The first step included the choice of search database, identifying terms relevant to the subject and implementing filters to the search engine (Step 1). After this first step, a manual screening was performed, in which all the titles and abstracts of the articles returned in the search were read in order to identify and remove any unrelated articles. A standardisation of terms was then performed, in which any repeated words or terms were identified and excluded. The data network was then constructed of all the articles using VOSviewer software (Step 2). The methodological procedures employed to achieve the results required are presented in the following methodological flowchart (Figure 1) and described below.

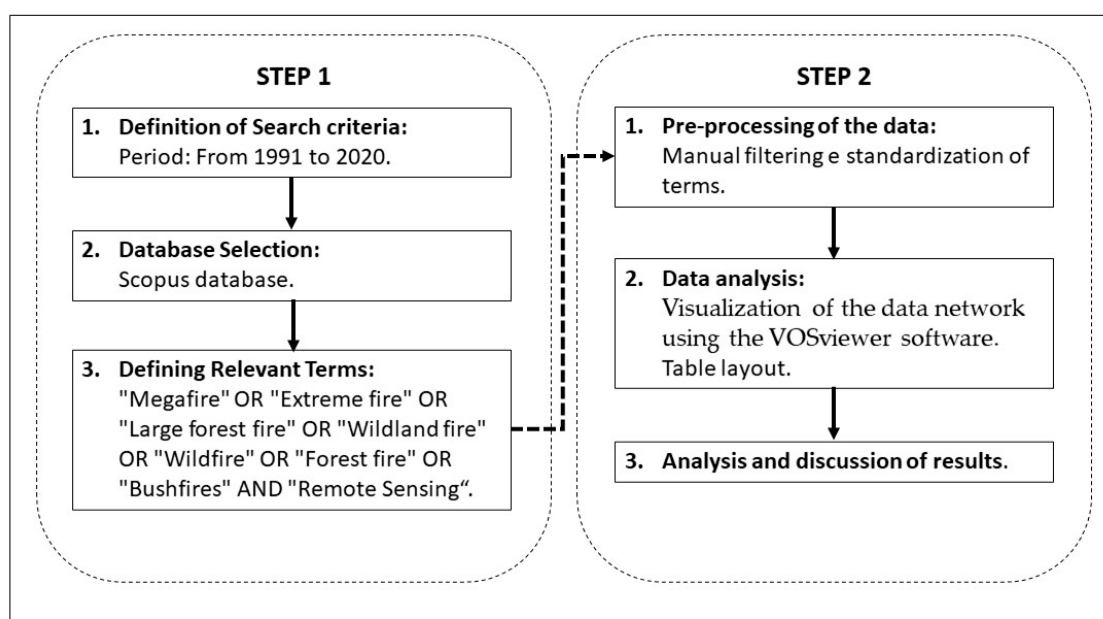


Figure 1. Methodology applied to the bibliometric analysis carried out.

2.1. Bibliographic Basis

The database used in this study was extracted from Scopus Database [40]. Scopus is the largest multidisciplinary database of abstracts and references of scientific literature, accounting for more than 25,100 titles, with about 23,452 of which being taken from peer-reviewed journals and 5000 from international publishers. Scopus offers the most comprehensive overview of world research production [27,40,41], incorporating efficient analysis tools to recover and aggregate information and export data in various formats, providing a comprehensive view of the total volume of global research produced in various areas of knowledge. All of these reasons contributed to Scopus being chosen as the bibliographic database used for this research [41].

This study was limited to an analysis of publications printed in journals, reducing the bias caused by duplicate publications and minimising false-positive results. Reviews, conference proceedings, book chapters, and books were not considered as they include works that may have been published more than once in different media sources [27].

To identify the articles published relating to the subject studied over the last 30 years, a search for related terms was performed using the Scopus [40] search tool. The possible textual variants that would allow for the research themes to be found in their totality were then determined, producing the following list: "Megafire" OR "Extreme fire" OR "Large forest fire" OR "Wildland fire" OR "Wildfire" OR "Forest fire" OR "Bushfires" AND "Remote Sensing". These terms were located in the titles, abstracts, and keywords of publications from between 1991 and 2020 on the 19 January 2021. Reviews and book chapters were removed from the search, as were articles unrelated to the subject.

2.2. Bibliometric Analysis

VOSviewer software [42,43] was used as a means through which to provide a visual representation of the data network. The tool is specifically designed for bibliometric analysis, and is used to view data returned by searches conducted in the Scopus Database (as well as other databases, such as Web of Science, Dimensions, PubMed) [42,43]. VOSviewer can be used to build networks of scientific publications, scientific journals, researchers, research organisations, countries, and keywords, for example. Items in these networks can be connected by co-authorship, co-occurrence, citation, bibliographic coupling, or co-citation links [27,28,30,43].

Creating a semantic network, the items are represented by nodes and edges. Nodes are objects such as co-authorship or co-occurrence of words and countries, for example. An edge can exist between any pair of nodes. An edge is a connection or relationship between two nodes. The distance between two nodes on the graph produced indicates the approximate relationship between search terms, and the relationship between the respective terms; smaller distances point to a greater number of co-occurrences. The size of a label on a node is determined by the weight of an item within a network (sizes have a direct correlation with frequency) [27–30,43].

All articles returned by the conducted search were analysed in terms of their textual and bibliographical data. Based on the textual data, co-occurrences were analysed between terms (in article titles and abstracts). Limiting the terms considered to the titles and abstracts of the articles reduced the risks of terms being repeated in different parts of the same documents being registered [28]. The research topics were categorised into four clusters based on when they were published: 1990s, 2000s, 2010s, and a comprehensive 30-year set.

The following analysis was performed using bibliographic data: bibliographic coupling (relationship between items based on the number of shared references); citation (relationship between items based on the number of times they cite each other); co-authorship (relationship of items based on the number of co-authored documents) and co-citation (relationship of items based on the number of times they are cited together) [28,43].

Each colour represents a cluster in the network visualisation maps obtained using VOSviewer software. These clusters were built by the software following the methodology described by Van Eck and Waltman [43] and Mourão [28]. VOSviewer constructs a map based on a co-occurrence matrix. The construction of a map is a process that consists of three steps. In the first step, a similarity matrix is calculated based on the co-occurrence matrix. In the second step, a map is constructed by applying the VOS mapping technique to the similarity matrix. Finally, in the third step, the map is translated, rotated, and reflected [43].

Other concepts presented in the figures and tables below are also explained in this publication. For example, a cluster is a group of items presented on a map; a link is a relationship between two items and average citations obtained by the documents within which an item appears.

3. Bibliometric Results and Discussion

The results found in the conducted bibliometric analysis shall be detailed in this section for sources, terms, countries, authors, citations, and co-citations. The number of documents obtained in the Scopus database (1722 documents, considering only articles and excluding books, conferences, and other documents) involving wildfires and remote sensing, published between 1991 and 2020.

3.1. General Information

An analysis of the annual distribution of the number of articles published on wildfires and remote sensing (see Figure 2) highlights the period between 2016 and 2020 as the most representative five-year period in the timeframe assessed, accounting for 40% of all publications. This period registers the highest growth rate in the number of publications. Due to the technological evolution that has occurred in recent years, with the development of new sensor systems, time series data, advances in image processing techniques, and the increased availability of free images have been established [26].

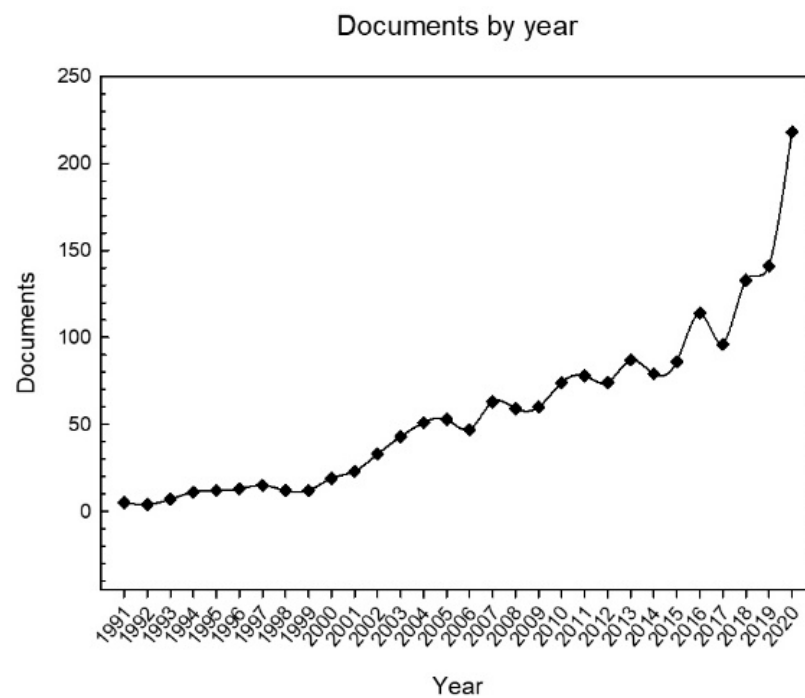


Figure 2. Annual growth in the number of publications on wildfires and remote sensing available in the Scopus database. The blue line indicates the trend of data behaviour. The points indicate the number of publications.

Of the 1722 publications, 951 (30.8%) were linked to the earth and planetary sciences subarea, 731(23.7%) with the environmental science subarea, 603 (19.6%) with the agricultural and biological sciences subarea, 193 (6.3%) with the social sciences subarea, 143 (4.6%) with the engineering subarea, 101 (3.3%) with the computer sciences subarea and the rest of the subareas present with low productivity on the subject.

3.2. Bibliographic Coupling and Journal Sources

Figure 3 presents the relationship between journals based on the number of references they share (bibliographic coupling \times journal sources). The *Remote Sensing of Environment* journal had an impact factor of 9.085 in 2019, and the *International Journal of Remote Sensing* registered an Impact Factor of 2.976 in 2019. These were the sources/journals with the most hits in the conducted search, accounting for half of the documents between them. These two publications were also the focus of most of the citations identified in the research. Strong relationships were registered between the following journals: *Remote Sensing of Environment*, *Remote Sensing*, *International Journal of Wildland Fire* and *International Journal of Remote Sensing*. The network was drawn up solely encompassing journals with at least eight publications, therefore containing only 43 journals and five clusters.

The size of each node (dot) and link (line) is proportional to the intensity of the node or line link. Table 1 presents additional information, listing the journals in order, from those with the most citations to the least, and according to the number of articles published. Table 1 also shows other relevant values such as the cluster number of each source, the value of its links and the strength of links.

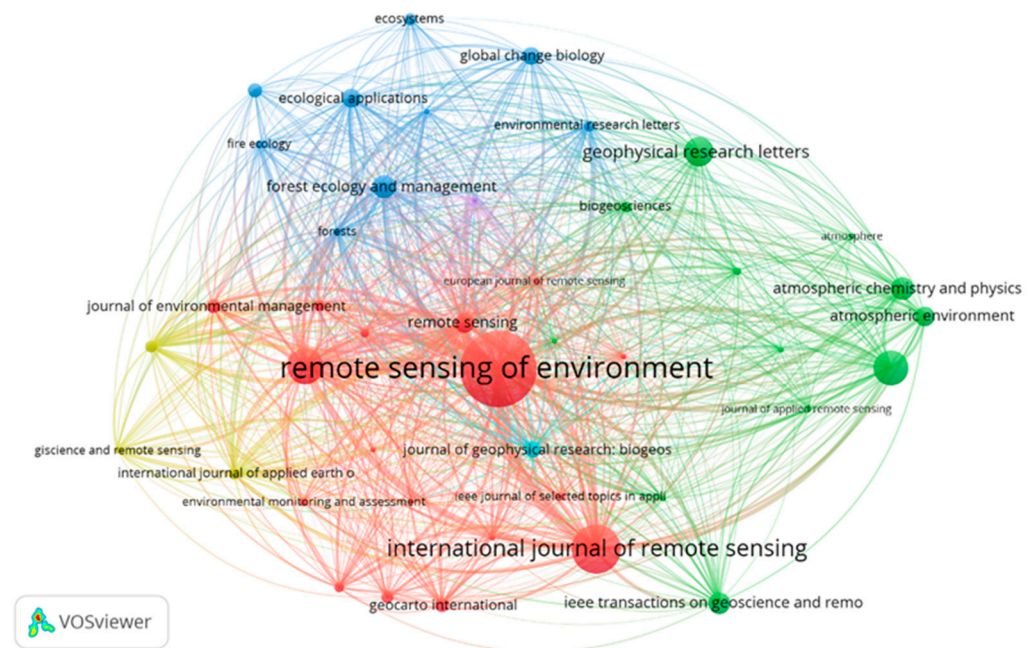


Figure 3. Network visualisation map based on bibliographic data (bibliographic coupling, journal sources).

Table 1. Journals publishing articles about the research area.

Title	Citations	Documents	Clusters	Link	Total Link-Strength
<i>Remote Sensing of Environment</i>	9777	133	1	42	3512.1
<i>International Journal of Remote Sensing</i>	4582	118	1	42	1724.61
<i>International Journal of Wildland Fire</i>	2745	77	1	42	1842.47
<i>Journal of Geophysical Research: Atmospheres</i>	2562	32	3	40	559.19
<i>Geophysical Research Letters</i>	1938	25	3	41	348.6
<i>Atmospheric Chemistry and Physics</i>	1253	23	3	42	468.02
<i>Forest Ecology and Management</i>	1210	43	2	42	1007.5
<i>IEEE Transactions on Geoscience and Remote Sensing</i>	1122	18	1	41	306.2
<i>Atmospheric Environment</i>	947	32	3	40	411.12
<i>Remote Sensing</i>	937	89	1	42	2111.45
<i>Ecological Applications</i>	852	18	2	42	607.42
<i>Global Change Biology</i>	819	15	2	42	520.55
<i>Journal of Geophysical Research: Biogeosciences</i>	736	15	2	41	554.91
<i>Landscape Ecology</i>	587	11	2	38	203.82
<i>Geocarto International</i>	574	17	1	42	260.05
<i>Journal of Environmental Management</i>	570	13	1	42	321.42
<i>International Journal of Applied Earth Observation and Geoinformation</i>	459	16	1	41	468.21
<i>ISPRS Journal of Photogrammetry and Remote Sensing</i>	438	17	4	42	660.48
<i>Photogrammetric Engineering and Remote Sensing</i>	406	18	1	42	219.73

Table 1. Cont.

Title	Citations	Documents	Clusters	Link	Total Link-Strength
<i>Ecosystems</i>	398	9	2	40	228.48
<i>Applied Geography</i>	369	12	1	41	278.58
<i>Environmental Research Letters</i>	361	20	2	42	451.01
<i>Biogeosciences</i>	352	9	2	42	276.08
<i>Natural Hazards</i>	292	14	1	42	304.76
<i>Environmental Management</i>	274	11	1	42	246.22
<i>Environmental Monitoring and Assessment</i>	213	12	1	41	162.3
<i>Forests</i>	206	27	2	42	892.94
<i>Fire Ecology</i>	186	11	2	41	295.57
<i>Science of the Total Environment</i>	182	10	3	41	237.59
<i>IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing</i>	176	15	1	41	249.06
<i>Izvestiya-Atmospheric and Ocean Physics</i>	133	12	4	40	100.4
<i>GIScience and Remote Sensing</i>	120	8	1	41	232.23
<i>Sensors (Switzerland)</i>	116	13	5	42	275.62
<i>Earth Interactions</i>	107	8	1	40	143.21
<i>Journal of the Indian Society of Remote Sensing</i>	101	18	1	41	174.16
<i>Journal of Applied Remote Sensing</i>	92	10	3	40	138.73
<i>Ecosphere</i>	91	8	2	42	247.43
<i>European Journal of Remote Sensing</i>	64	8	1	42	224.75
<i>Sovremennyye Problemy Distantionnogo Zondirovaniya Zemli Iz Kosmosa</i>	38	13	4	41	96.03
<i>Atmosphere</i>	36	9	3	38	145.53
<i>Fire</i>	26	9	5	42	323.46
<i>Beijing Linye Daxue Xuebao/Journal of Beijing Forestry University</i>	16	10	4	25	13
<i>Yaogan Xuebao/Journal of Remote Sensing</i>	7	11	1	41	134.96

VOSviewer generates clusters considering the individual publications in focus [43]. In this specific case, each source was analysed as an individual and was exclusively grouped into one community; each was built considering the relevance of the specific variable. Consequently, 43 items were displayed in five clusters. In total, 19 items were grouped into cluster 1, which is composed of the most cited sources. This phenomenon is not uncommon in bibliometric analyses [28,44] and reflects a certain publishing preference among journals, which publish articles that cite other works within certain groups of journals, especially those with similar impact factors [28,45].

3.3. Citation of Sources

In this case, connections between items were based on the number of times journals cited each other (Figure 4). It can be concluded that the *Remote Sensing of Environment* journal (which contained 113 documents, 9777 citations and had a link-strength of 1024), the *International Journal of Remote Sensing* (118 documents, 4582 citations and a link-strength of 497), the *Journal Remote Sensing* (89 documents, 937 citations and a link-strength of 365) and the *International Journal of Wildland Fire* (77 documents, 2745 citations and link-strength of 477) were the sources with the most frequently cited documents. These four publications make up about 44.7% of the total citations registered.

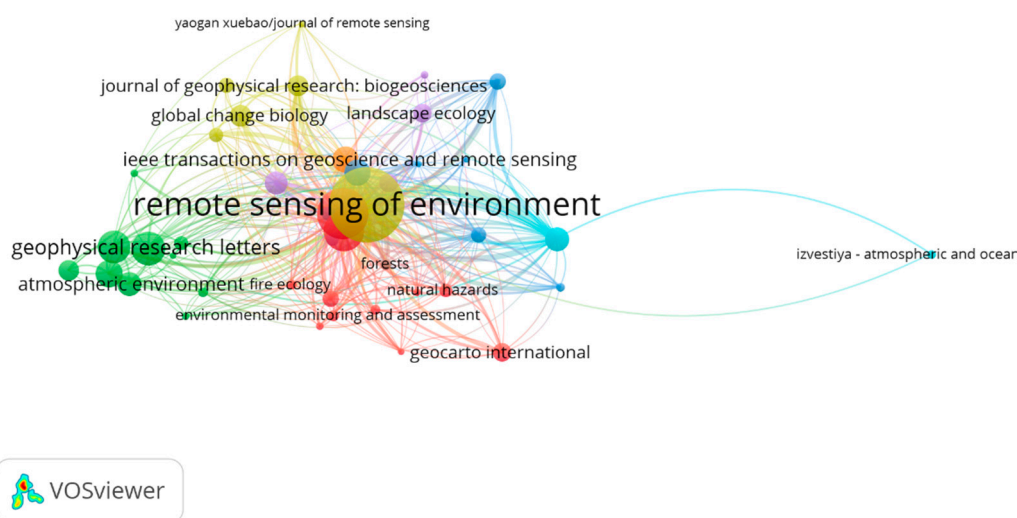


Figure 4. Network visualisation map based on bibliographic data (citation, sources). Caption: The size/width of each node (“dot”) and link (“line”) is proportional to the intensity of the node or link.

The *Izvestiya-Atmospheric and Ocean Physics* journal does not show a strong relationship to the others and is placed in an isolated position within the network. It is also important to note that *Yaogan Xuebao/Journal of Remote Sensing* did not link to any of the journals in the “citation x sources” analysis. However, this journal was still included in the journals with at least eight publications on the research subject.

3.4. Main Terms

Based on the textual data located in the titles, abstracts, and keywords of the articles, and using the frequency of co-occurrence to analyse the textual data, only the terms repeated at least 10 times were considered, repeated terms having been identified and adjusted in the pre-processing phase of the data. The research topics were categorised into four clusters (represented using different colours in Figure 5), with the following composition over time: 1990s (1991 to 2000, 30 terms analysed in three clusters), 2000s (2001 to 2010, 288 terms analysed in four clusters), 2010s (2011 to 2020, 641 terms analysed in four clusters), and a comprehensive 30-year set (1991 to 2020, 951 terms analysed).

The network established for the 1990s (1991 to 2000, see Figure 5) allowed three clusters to be identified. In the first one, the most frequent terms were “data”, “change”, “wildfire”, “analysis”, and “effect”. The second cluster contained the terms: “forest fire”, “fire”, “image”, “burned area”, “detection”. The third contained the terms: “remote sensing”, “use”, “monitoring”, “gis”, “observation”. These results reflect the major scientific interests present in the 1990s within the discussion on the techniques used for conducting image analyses on forest fire research, as well as on the development of remote sensing tools used to analyse changes in land use, monitoring and landscape dynamics related to forest fires [46,47].

Between 2001 and 2010 (Figure 5), a growing number of terms and a consequent increment in the number of network clusters can be identified. The four clusters identified for this period are as follows: (1) cluster one contains the terms “Forest fire”, “satellite”, “detection”, “estimation”, “system”, “use”; (2) cluster two contains “model”, “remote sensing data”, “observation”, “emission”, “modis”, “carbon”; (3) the third cluster contains: “analysis”, “index”, “severity”, “image”, “ndvi”, “nbr”; (4) the fourth cluster contains: “fire”, “forest”, “wildfire”, “landscape”, “change”, “effect”. New trends in scientific research have appeared during this period, focusing on establishing models used to analyse forest fires and develop different analysis indexes [7,48–52].

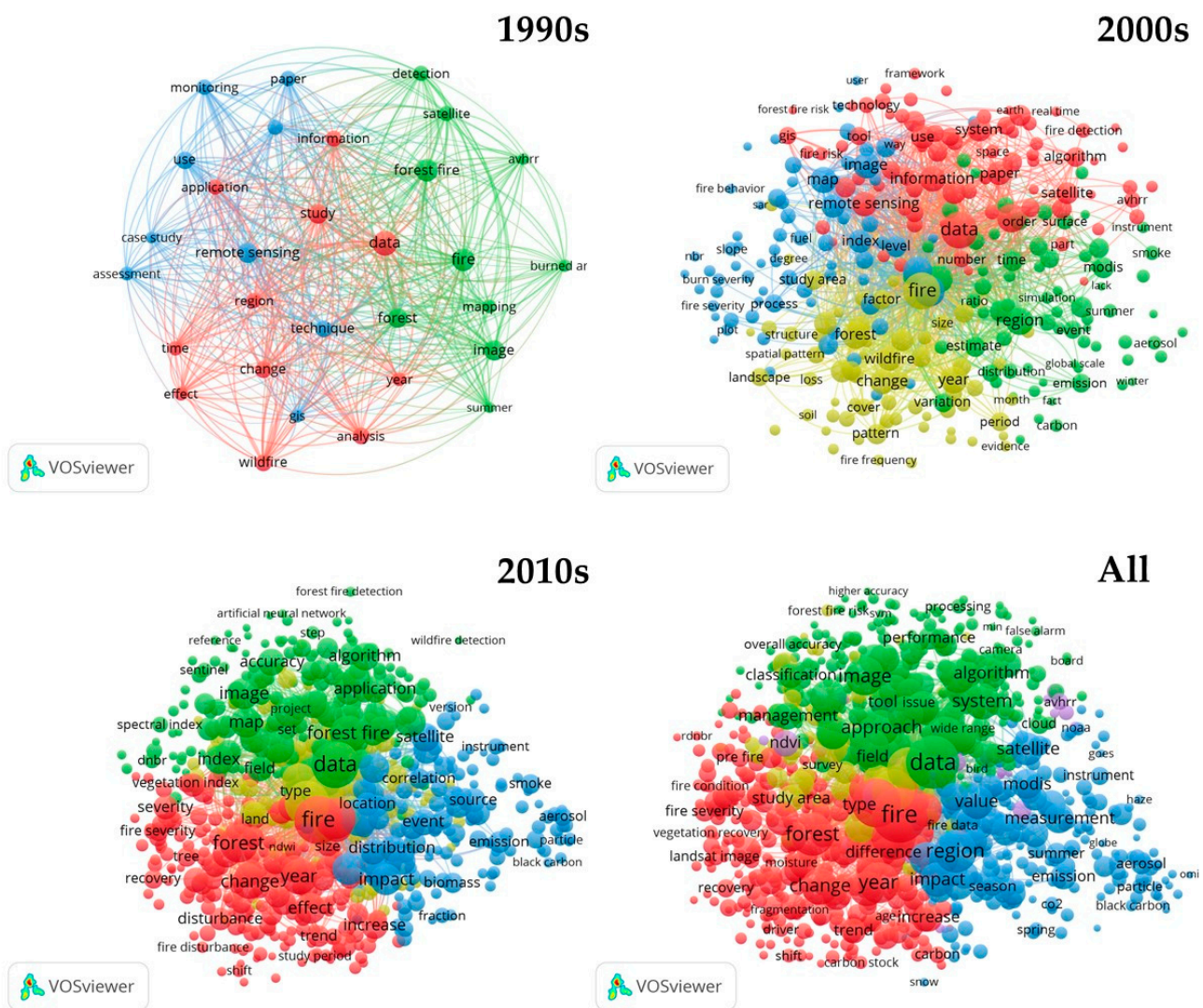


Figure 5. Word co-occurrence network presented in titles, abstracts, and keywords for each decade (the 1990s, 2000s and 2010s) and all scientific articles published in the 30-year time frame (1991–2020).

The last decade included in this analysis (2011–2020, see Figure 5) also presents a network containing four clusters, revealing the consolidation of the use of some terms (relating to some topics), such as fire, data, forest fire, change, index, analysis. The main terms in the first cluster are: “fire”, “forest”, “wildfire”, “change”, “effect”, “severity”, “landscape”; in the second cluster are: “data”, “forest fire”, “image”, “accuracy”, “index”, “algorithm”, “system”; third cluster: “event”, “region”, “observation”, “satellite”, “modis”, “impact”, “emission”; and for the fourth cluster: “remote sensing”, “analysis”, “study”, “land cover”, “occurrence”. The distribution of this set of terms reveals a certain consolidation of some research topics, specifically those related to clusters one and two, as well as the emergence of other topics related to the application of spectral indices for the analysis of the severity of fires and the development of application systems and algorithms for use in satellite imagery processing and analysis [9,10,53–55].

If the development of the network as a whole, encompassing the entirety of the period studied, is considered (1991–2020, see Figure 5), the existence of a well-established network of terms is established, exposing a clear conceptual framework resulting from the interconnection of studies involving forest fires and remote sensing. In fact, in cluster one, the emergence of research topics related to the analysis of changes in forest areas following forest fires can be perceived based on the application of spectral indexes and concerning the impact of such events on climate change. Cluster two addresses topics associated with

wildfire detection, monitoring and mapping based on satellite imagery. The third cluster demonstrates the relationship between terms connected to the impact of fire, fire emissions, pollution, distribution and value. The final cluster is centred on research topics that assess burnt areas by implementing models applied to remote sensing data. The influence of anthropic factors is also included in this cluster [7,26,46,49,52–56].

3.5. Countries

The nationalities of co-authors were determined in order to pinpoint collaborations established between countries. The search conducted of the Scopus database returned publications from 106 countries and 26 publications with no country identified.

Figure 6 demonstrates that the countries identified in the analysis were grouped into seven clusters (see Table 2). The criteria defined for the selection of countries were those that produced journals with a minimum of 10 published documents and a minimum of 50 citations. A total of 33 countries were selected as a result, with most co-authored documents being registered as from the USA (681 documents, 30% of the studies), China (192 documents, 8.4% of the studies), Spain (176 documents, 7.7% of the studies), and Canada (142 documents, 6.2% of the studies); these four countries make up around 52.3% of the studies among the 33 countries analysed. These analyses of the various co-authorships reveal the international cooperation between authors of different nationalities and affiliations in terms of the themes explored here and related to forest fires and remote sensing.

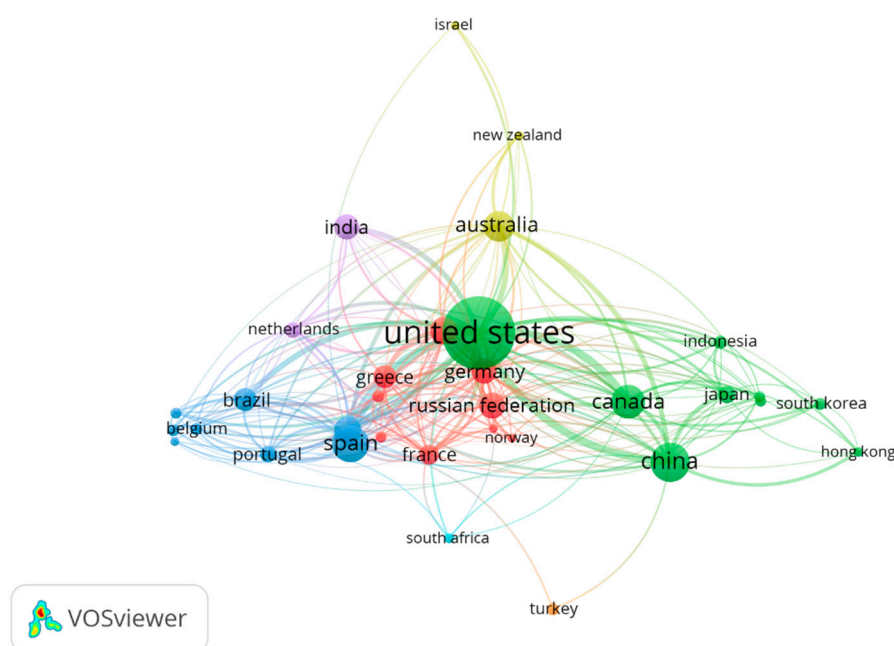


Figure 6. Network visualisation map based on bibliographic data (co-authorship, countries).

Table 2. Countries to which authors are affiliated.

Country	Clusters	Documents	Citations	Total Link-Strength	Link
United Kingdom		91	4004	78	23
Russia		88	1661	31	16
Germany		77	3062	56	26
Greece		64	1385	33	16
France	1	51	1791	36	22
Finland		20	627	13	15
Switzerland		16	787	14	13
Norway		11	443	9	12
Austria		10	218	9	12

Table 2. Cont.

Country	Clusters	Documents	Citations	Total Link-Strength	Link
United States		681	27,655	212	31
China		191	2840	82	22
Canada		141	4496	67	25
Japan		40	783	26	17
Indonesia	2	22	397	15	8
South Korea		17	157	7	8
Malaysia		15	216	9	17
Iran		14	284	8	7
Hong Kong		12	237	10	6
Spain		175	6137	71	22
Italy		96	2934	51	22
Brazil		63	1800	35	15
Portugal	3	36	894	24	18
Belgium		19	679	16	13
Chile		17	344	11	11
Mexico		16	291	11	8
Argentina		11	264	4	8
Australia		119	3593	58	23
Israel	4	10	316	4	3
New Zealand		10	787	9	6
India	5	77	1346	22	9
Netherlands		29	1066	26	15
South Africa	6	12	202	5	6
Turkey	7	17	158	2	2

As expected, the network of collaborations between different nationalities had a positive correlation with the co-citation of works [28]. Table 2 presents additional information quantifying the data presented in Figure 6, displaying the way in which relationship clusters are organised according to the number of publications, citations, and strength of links. The table also shows the interrelations between countries, allowing the data to be considered in terms of trends through the network of publications among countries. It is also possible to observe that the countries with more significant link-strengths in the groups are: United Kingdom (cluster 1), United States (cluster 2), Spain (cluster 3), Australia (cluster 4), India (cluster 5), South Africa (cluster 6) and Turkey (cluster 7). Portugal and Brazil are part of cluster 3, collaborating more closely with Spain, Italy, Belgium, Chile, Mexico, and Argentina.

The USDA Forest Service ranks first among the institutes that have published the most (Table 3). Among the top 20 publishers, 15 are from the United States, two are Chinese, two Canadian, and one is a European centre based in Belgium.

3.6. Authors and Co-Citation

To understand whether the scientific topics addressed within this article tend to be more or less concentrated in terms of their authorship, this subsection shall analyse the most productive authors, co-authorships, and co-citations individually. The following Table 4 therefore presents the single authors with the highest number of publications and citations related to forest fires and remote sensing, as established by the conducted search.

Table 3. The 20 institutes to have published the most articles on wildfires and remote sensing worldwide.

n°	Publication Affiliation	NP	Countries
1	USDA Forest Service	123	United States
2	Chinese Academy of Sciences	73	China
3	University of Maryland	69	United States
4	NASA Goddard Space Flight Centre	65	United States
5	United States Geological Survey	58	United States
6	University of Idaho	33	United States
7	United States Department of Agriculture	31	United States
8	University of Colorado Boulder	31	United States
9	Canadian Forest Service	29	Canada
10	USDA ARS Rocky Mountain Research Station	29	United States
11	Jet Propulsion Laboratory	28	United States
12	Oregon State University	28	United States
13	European Commission Joint Research Centre	27	Belgium
14	University of Chinese Academy of Sciences	27	China
15	Science Systems and Applications, Inc. SSAI	26	United States
16	The University of British Columbia	25	Canada
17	USDA ARS Moscow Forestry Sciences Lab	25	United States
18	University of Alaska Fairbanks	25	United States
19	California Institute of Technology	25	United States
20	NASA Ames Research centre	24	United States

Table 4. Most productive authors.

Author	Documents	Citations	Affiliation	Countries
Chuvieco E.	7	501	University of Alcalá	Spain
Hassan Q. K.	5	82	University of Calgary	Canada
Kinoshita A. M.	4	81	San Diego State University	United States
Sunar F.	4	65	Istanbul Technical University	Turkey

3.6.1. Co-Authorship

When analysing the authors returned in the search from the angle of co-authorship, authors were required to have at least four documents. In order to create links, the relationship between items was based on the number of documents co-authored. Figure 7 presents the network visualisation map of these items and reveals that the various authors were grouped into 18 clusters. Some of the 245 items identified in the network did not connect to any others, with the largest set of interconnected items therefore consisting of 206 items.

In these groups, the authors with the most co-authored documents were Emilio Chuvieco (19 studies), Z. Li (19 studies), and A. T. Hudak (18 studies). Table 5 also details the number of citations of the ten most productive groups. All these authors have been cited a high number of times, demonstrating their significant contribution to the research topic of this paper.

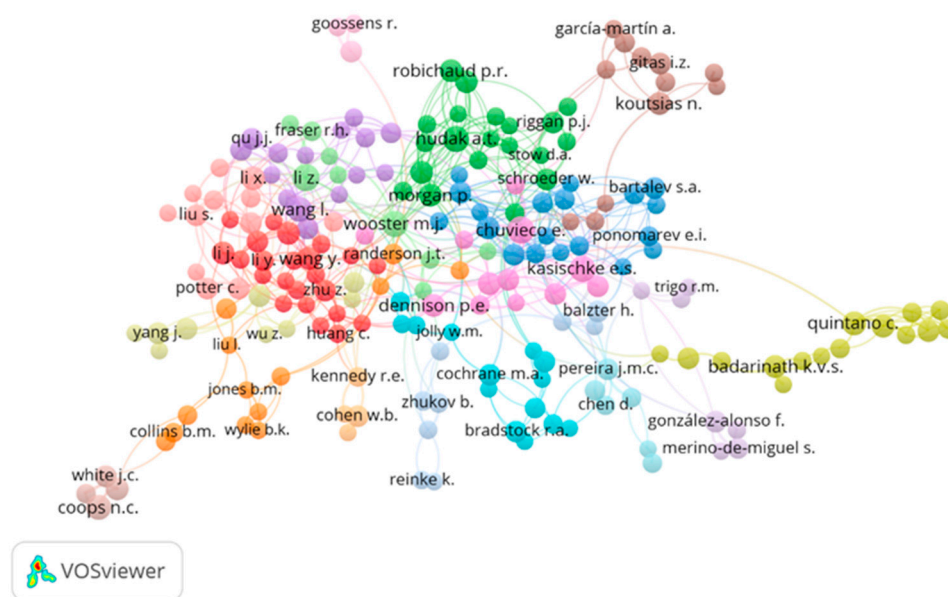


Figure 7. Network visualisation map based on bibliographic data (co-authorship, authors).

Table 5. List of the 10 most cited co-authors within the most productive clusters.

Author	Documents	Citations	Affiliation	Countries
Kaufman Y. J.	4	2058	NASA Goddard Space Flight Centre	United States
Justice C. O.	9	1992	NASA Goddard Space Flight Centre	United States
Giglio L.	10	1791	University of Maryland	United States
Chuvieco E.	19	1447	University of Alcalá	Spain
Wooster M. J.	16	1194	Department of Geography, King's College London	United Kingdom
Kasischke E.S.	16	1006	Environmental Research Institute of Michigan	United States
Dennison P. E.	10	952	University of Utah	United States
Perry G. L. W.	5	909	University of Canterbury	New Zealand
Cohen W. B.	9	752	USDA Forest Service	United States

3.6.2. Co-Citation

For links focussing on co-citation, the relationship between the items was based on the number of times cited together. Only authors with a minimum of 50 citations were selected for the analysis. Figure 8 shows that L. Giglio and E. Chuvieco are the most co-cited authors (1273 and 1263 citations, respectively). Other authors with a significant number of citations and with a pronounced relatedness are C. O. Justice (995 citations), E. S. Kasischke (831 citations), and Y. J. Kaufman (708 citations).

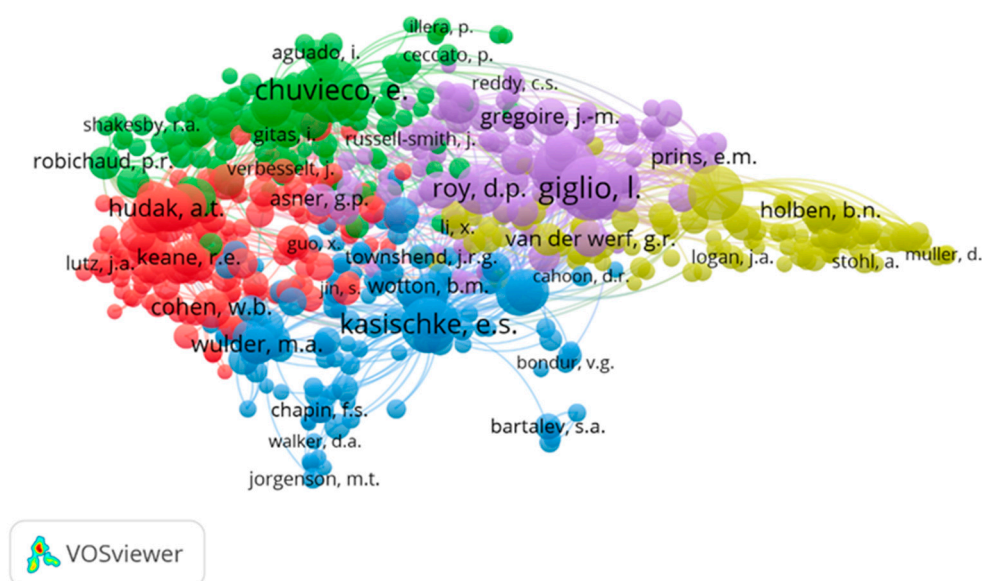


Figure 8. Network visualisation map based on bibliographic data (co-citation, cited authors).

4. Conclusions

The bibliographic revision performed within this work centred on publications on the subject of wildland fires and remote sensing in scientific journals that were published in the last three decades (1991–2020). It was possible to identify the leading journals, countries, authors, and institutions involved in the research conducted on the above-mentioned topics and map out the most relevant terms used over this period.

The results show that the number of publications on the subjects increased during the period analysed, demonstrating the growing interest of the scientific community. Of the total publications, 54% were linked to earth and environmental sciences, revealing the interest and connection between the topics analysed and the environmental dynamics. The research trends in this field include the significant developments in remote sensing techniques for studies on forest fires in recent decades. This evolution is explained by the fact that there is a strong correlation between the technological evolution of detection methods and remote sensing data acquisition.

It was also concluded that publications with the highest number of articles and citations were scientific journals, specifically Elsevier's *Remote Sensing of Environment* (IF 2019: 9.085) journal, Taylor and Francis' *International Journal of Remote Sensing* (IF 2019: 2976) and Csiro Publishing's *International Journal of Wildland Fire* (IF 2019: 2988).

In terms of researchers' countries of origin, the United States of America was the highest contributor, providing 681 co-authored documents, and was also the country with the highest number of international co-operations. China contributed 192 documents, Spain contributed 176 and Canada contributed 142. Consequently, the research institutions with higher contribution rates come from these countries: the USDA Forest Service coming in first place, followed by the Chinese Academy of Sciences and the University of Maryland.

Regarding the most frequent indicators in publications, evolution of the theoretical and methodological field was noted over the three decades analysed. A well-established network was also found to exist between the terms, creating four major relationship clusters. The first cluster involved analysing changes in forests caused by wildland fires over the years and the use of spectral indices in the analysis of climate change. A second cluster involved developing systems to monitor, map and detect wildland fires based on satellite imagery. The third cluster demonstrates the relationship between studies on the impact of emissions, especially in the various biomes. The fourth cluster demonstrates the relationship between studies that analyse burnt areas based on models, using remote sensing data as well as the influence of anthropogenic factors.

Considering the authors with the highest levels of published scientific work identified in this paper, it can be concluded that Emilio Chuvieco has produced the most on the topic studied, both individually and collaboratively. The most cited authors are Y. J. Kaufman (2130 citations), C. O. Justice (1971 citations), L. Giglio (1770 citations) and E. Chuvieco (1413 citations). L. Giglio and E. Chuvieco are the most cited co-authors (1286 and 1261 citations, respectively).

This work presents certain limitations, some of which will serve as a basis for future research. First, the bibliometric analysis could also be developed using other quantitative or qualitative tools (for example, Web of Science or Google Scholar), which may present some differences, especially concerning citations. As databases are not updated immediately once an article is published, slight variations may exist in the number of articles present in the WoS and Scopus databases.

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